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THE FISHERY FOR TUNAS AND BILLFISHES IN THE EASTERN PACIFIC OCEAN IN 2006

SECTION J: ECOSYSTEM CONSIDERATIONS

1. Introduction 1
2. Impact of catches 2
3. Other ecosystem components 7
4. Trophic interactions 9
5. Physical environment 10
6. Aggregate indicators 11
7. Ecosystem modeling 12
8. Actions by the IATTC and the AIDCP addressing ecosystem considerations 13
9. Future developments 15

1. INTRODUCTION

The FAO Code of Conduct for Responsible Fisheries provides that management of fisheries should ensure the conservation not only of target species, but also of the other species belonging to the same ecosystem. In 2001, the Reykjavik Declaration on Responsible Fisheries in the Ecosystem elaborated this standard with a commitment to incorporate an ecosystem approach into fisheries management.

The IATTC has taken account of ecosystem issues in many of its decisions, but until recently has not focused its attention on the entire ecosystem in which the target species, the tunas and billfishes, reside. This section provides a coherent view, summarizing what is known about the direct impact of the fisheries upon various species and species groups of the ecosystem, and reviews what is known about the environment and about other species that are not directly impacted by the fisheries. The purpose is to provide the Commission with the opportunity to consider the entire ecosystem as part of its consideration of the status of the tuna and billfish stocks and management measures.

This review does not suggest objectives for the incorporation of ecosystem considerations into the management of tuna or billfish fisheries, nor any new management measures. Rather, its prime purpose is to offer the Commission the opportunity to ensure that ecosystem considerations are clearly part of its agenda.

It is important to remember that the view that we have of the ecosystem is based on the recent past; we have almost no information about the ecosystem before exploitation began. Also, the environment is subject to change on a variety of time scales, including the well-known El Niño fluctuations and more recently recognized longer-term changes, such as the Pacific Decadal Oscillation and other climate changes.

In addition to reporting the catches of the principal species of tunas and billfishes, the staff has reported the bycatches of other species that are normally discarded. In this section, data on these bycatches are presented in the context of the effect of the fishery on the ecosystem. Unfortunately, while relatively good information is available for the tunas and billfishes, information for the entire fishery is not available. The information is comprehensive for large (carrying capacity greater than 363 metric tons) purse seiners that carry observers under the Agreement on the International Dolphin Conservation Program (AIDCP), and information on retained catches is also reported for other purse seiners, pole-and-line vessels, and much of the longline fleet. Some information is available on sharks that are retained by parts of the longline fleet. Information on bycatches and discards is also available for large purse-seiners, and for some smaller ones. There is little information available on the bycatches and discards for other fishing vessels.

2. IMPACT OF CATCHES

2.1. Single-species assessments

This section provides a summary of current information on the effects of the tuna fisheries on the stocks of individual species in the eastern Pacific Ocean (EPO). It focuses on the current biomass of each stock considered, compared to what it might have been in the absence of a fishery. The intention is to show how the fishery may have altered the components of the ecosystem, rather than the detailed assessments, which can be found in other sections of this report and in other Commission documents. The section below frequently refers to comparisons with the estimated unexploited stock size. There are no direct measurements of the unexploited stock size, and, in any case, it would have varied from year to year. In addition, the unexploited stock size may be influenced by predator and prey abundance, which is not included in the single species analyses.

2.2. Tunas

2.2.1. Yellowfin (*Thunnus albacares*)

The yellowfin stock changed into a higher productivity regime in about 1985, but may have recently moved back into a lower productivity regime. For the last three years the yellowfin stock has been below the level corresponding to the average maximum sustainable yield (36% of its unexploited size). One estimate of the effect of this reduced stock size is that the predation by yellowfin on other parts of the ecosystem is reduced to about 30% of what it was in the absence of a fishery.

2.2.2. Skipjack (*Katsuwonus pelamis*)

Skipjack assessments are far less certain than those for yellowfin and bigeye, in part because the fishery in the EPO does not appear to be having much impact on the stock. However, it appears that fluctuations in recruitment cause large variations in stock size. In 2003, the biomass was estimated to be about 60% of what it would have been in the absence of a fishery and under average conditions.

2.2.3. Bigeye (*Thunnus obesus*)

Up to 1993, bigeye were taken mostly by longline fishing. The stock size in 1993 is estimated to have been 28% of its unexploited size. After 1993, purse seining for tunas associated with fish-aggregating devices (FADs) took significant quantities of small and medium-sized bigeye. In 2004, after several years of poor recruitment and excessive levels of fishing mortality, the stock size was estimated to be at about 13% of its unexploited size. Due to recent spikes in recruitment, the current level has increased to 20%.

2.2.4. Pacific bluefin (*Thunnus orientalis*)

It is likely that there is a single stock of Pacific bluefin tuna in the Pacific Ocean, given that spawning is known to occur only in the western Pacific Ocean. However, tagging studies have shown that there is exchange of bluefin between the eastern and western Pacific Ocean. A preliminary stock assessment, carried out by the International Scientific Committee of the North Pacific in 2005, has indicated that the biomass of the spawning stock had local peaks during the early 1960s, late 1970s and late 1990s, with a decline after the last peak. A strong recruitment event that may have occurred in 2001 would maintain spawning stock biomass above recent levels until 2010.

2.2.5. Albacore (*Thunnus alalunga*)

It is generally considered that there are two stocks of albacore in the Pacific Ocean, one in the North Pacific and the other in the South Pacific. An assessment for South Pacific albacore, done by the Secretariat of the Pacific Community in 2003, showed that the South Pacific stock was at about 60% of its unexploited size. An assessment by the 19th North Pacific Albacore Workshop in 2004 indicated the North Pacific stock to be at about 45% of its unexploited size.

2.3. Billfishes

2.3.1. Swordfish (*Xiphias gladius*)[1]

The northeastern and southeastern Pacific Ocean stocks of swordfish are distinctly identifiable by genetics and fisheries analyses. Preliminary analyses of the status of the southeastern Pacific Ocean stock of swordfish indicate that the spawning biomass has declined significantly over the 1945-2003 period, and is now about twice the level (~0.26) which will support fisheries at average maximum sustained yield (AMSY = 13,000 – 14,000 t). Catches have increased substantially since 2001. Recent harvests are on the order of 14,000 – 15,000 t of swordfish annually.

The variations in standardized catch per unit of effort (CPUE) of swordfish in the northern EPO show no trend, suggesting that catches to date have not affected the stock significantly.

2.3.2. Blue marlin (*Makaira nigricans*)

Recent stock assessments of blue marlin suggest that the current stock size is between 50 and 90% of the unexploited stock size.

2.3.3. Striped marlin (*Tetrapturus audax*)

Preliminary genetics analysis suggest there are separate striped marlin stocks in the Pacific Ocean. Assessments for the EPO stock suggested that the current stock size is about 50 to 70% of the unexploited stock size. An analysis of the status of an hypothesized stock of striped marlin spanning the entire north Pacific was recently conducted. The results suggested a decline in stock size, however results were considered provisional.

2.3.4. Black marlin (*Makaira indica*), sailfish (*Istiophorus platypterus*), and shortbill spearfish (*Tetrapturus angustirostris*)

No recent stock assessments have been made for these species, although there are some data presented in the IATTC Bulletin series published jointly by scientists of the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan and the IATTC that show trends in catches, effort, and CPUEs.

2.4. Summary

The estimated catches[2] (including purse-seine discards), in metric tons, of tunas and billfishes in the EPO during 2006 are as follows.

	PS			LP	LL	OTR	Total
	OBJ	NOA	DEL				
Yellowfin tuna	35,642	41,914	89,182	693	2,264	3,293	
Skipjack tuna	194,679	108,527	4,942	429	120	9,405	
Bigeye tuna				0	30,019	8	
Pacific bluefin		9,795		0	0	96	
Albacore tuna	0	109	0	0	5,742	6,506	12,357
Swordfish				0	469	222	

[2] Preliminary data

Blue marlin	0		156
Striped marlin	0		92
Black marlin	0	0	
Sailfish	0	26	593
Shortbill spearfish	0		

2.5. Marine mammals

Marine mammals, especially spotted dolphins (*Stenella attenuata*), spinner dolphins (*S. longirostris*), and common dolphins (*Delphinus delphis*), are frequently found associated with yellowfin tuna in the size range of about 10 to 40 kg in the EPO. Purse-seine fishermen have found that their catches of yellowfin in the EPO can be maximized by setting their nets around herds of dolphins and the associated schools of tunas, and then releasing the dolphins while retaining the tunas. The incidental mortality of dolphins in this operation was high during the early years of the fishery, and the populations of dolphins were reduced from their unexploited levels during the 1960s and 1970s. After the late 1980s the incidental mortality decreased precipitously, and there is now evidence that the populations are recovering. Preliminary mortality estimates of dolphins in the fishery in 2006 are as follows:

Species and stock	Incidental mortality	
	Number	tons
Offshore spotted dolphin		
Northeastern	144	9
Western-southern	135	9
Spinner dolphin		
Eastern	155	7
Whitebelly	157	9
Common dolphin		
Northern	130	9
Central	87	6
Southern	38	3
Other dolphins[3]	40	4
Total	**886**	**57**

Studies of the association of tunas with dolphins have been an important component of the staff's long-term approach to understanding key interactions in the ecosystem. The extent to which yellowfin tuna and dolphins compete for resources, or whether either or both of them benefits from the interaction, remain critical pieces of information, given the large biomasses of both groups and their high rates of prey consumption. Diet and stable isotope analyses of yellowfin tuna and spotted and spinner dolphins caught in polyspecific aggregations by purse seine vessels in the EPO demonstrate significant differences in food habits and trophic position of the three species, suggesting that the tuna-dolphin association is probably not maintained by feeding advantages. This conclusion is supported by radio tracking studies of spotted dolphins outfitted with time-depth recorders, which indicate that the dolphins feed primarily at night on organisms associated with the deep scattering layer, while food habits studies of yellowfin tuna show primarily daytime feeding.

During 2006, scientists of the U.S. National Marine Fisheries Service (NMFS) conducted the latest in a series of research cruises under the *Stenella* Abundance Research Project (STAR). The primary objective of the multi-year study is to investigate trends in population size of the dolphins that have been taken as

[3] "Other dolphins" includes the following species and stocks, whose observed mortalities were as follows: striped dolphins 6 (0.4 t); Central American spinner dolphins (*Stenella longirostris centroamericana*) 6 (0.3 t); bottlenose dolphins 3 (0.3 t), shortfin pilot whales (*Globicephala macrorhynchus*) 2 (1.3 t), coastal spotted dolphins 3 (0.3 t); unidentified dolphins 20 (1.1 t).

incidental catch by the purse-seine fishery in the EPO. Data on cetacean distribution, herd size, and herd composition were collected to estimate dolphin abundance. The 2006 survey covered the same areas and used the same methods as past surveys. Data from the large-scale line-transect survey of 2003 produced abundance estimates for 10 dolphin species and/or stocks. The estimates for northeastern offshore spotted and eastern spinner dolphins for 2003 were somewhat higher than the estimates from the previous surveys in 1998-2000, and weighted linear regressions indicated a small positive trend in the abundance over the years 1979-2003, The estimates for western/southern offshore spotted, whitebelly spinner, striped (*S. coeruleoalba*), rough-toothed (*Steno bredanensis*), common, bottlenose (*Tursiops truncatus*), and Risso's (*Grampus griseus*) dolphins were generally similar to previous estimates using the same methods.

Scientists of the NMFS have made estimates of the abundances of several other species of marine mammals based on data from research cruises made between 1986 and 2000 in the EPO. The STAR 2003 and upcoming 2006 cruises will provide further estimates of abundance of these mammals. Of the species not significantly affected by the tuna fishery, short-finned pilot whales (*Globicephala macrorhynchus*) and three stocks of common dolphins showed increasing trends in abundance during that 15-year period. The apparent increased abundance of these mammals may have caused a decrease in the carrying capacity of the EPO for other predators that overlap in diet, including spotted dolphins. Bryde's whales (*Balaenoptera edeni*) also increased in estimated abundance, but there is very little diet overlap between these baleen whales and the upper-level predators impacted by the fisheries. Striped dolphins (*Stenella coeruleoalba*) showed no clear trend in estimated abundance over time, and the estimates of abundance of sperm whales (*Physeter macrocephalus*) tended to decrease in recent years.

Some marine mammals are adversely affected by reduced food availability during El Niño events, especially in coastal ecosystems. Examples that have been documented include dolphins, pinnipeds, and Bryde's whales off Peru, and pinnipeds around the Galapagos Islands. Large whales are able to move in response to changes in prey productivity and distribution.

2.6. Sea turtles

Sea turtles are caught on longlines when they take the bait on hooks, are snagged accidentally by hooks, or are entangled in the lines. Estimates of incidental mortality of turtles due to longline and gillnet fishing are few. At the 4th meeting of the IATTC Working Group on Bycatch in January 2004, it was reported that 166 leatherback (*Dermochelys coriacea*) and 6,000 other turtle species, mostly olive Ridley (*Lepidochelys olivacea*), were incidentally caught by Japan's longline fishery in the EPO during 2000, and that, of these, 25 and 3,000, respectively, were dead. At the 6th meeting of the IATTC Working Group on Bycatch in February 2007, it was reported that the Spanish surface longline fleet targeting swordfish in the EPO averaged 65 interactions and 8 mortalities per million hooks[4] during 1990-2005. The mortality rates due to longlining in the EPO are likely to be similar for other fleets targeting bigeye tuna, and possibly greater for those that set lines at shallower depths for albacore and swordfish. About 23 million of the 200 million hooks set each year in the EPO by distant-water longline vessels target swordfish with shallow longlines.

In addition, there is a sizeable fleet of locally-based longline vessels that fish for tunas and billfishes in the EPO. During 2005, staff members of the IATTC and some other organizations rendered advice and assistance to the governments of several Latin American nations bordering on the Pacific Ocean to reduce the mortality of sea turtles caused by the artisanal longline fishery for tunas and other species. Additional information on this program can be found in Section 8.2.

Sea turtles are occasionally caught in purse seines in the EPO tuna fishery. Most interactions occur when the turtles associate with floating objects, and are captured when the object is encircled. In other cases, nets set around unassociated schools of tunas or schools associated with dolphins may capture sea turtles that happen to be at that location. The olive Ridley turtle is, by far, the species of sea turtle taken most often by purse seiners. It is followed by black or green sea turtles (*Chelonia agassizi*), and, very occasionally, by loggerhead (*Caretta caretta*) and hawksbill (*Eritmochelys imbricata*) turtles. Only one mortality of a leatherback turtle has been recorded during the 10 years that IATTC observers have been recording this information. Some of the turtles are unidentified because they were too far from the vessel or it was too dark for the observer to identify them. Sea turtles, at times, become entangled in the webbing under fish-aggregating devices (FADs) and drown. In some cases, they are entangled by the fishing gear and may be injured or killed. The estimated mortalities[4] (in numbers) of turtles caused by large purse-seine vessels during 2006 were as follows:

	Set type		
	OBJ	**NOA**	**DEL**
Olive Ridley			
Black or eastern Pacific green			
Loggerhead			
Hawksbill			
Leatherback			
Unidentified			
Total			

The mortalities of sea turtles due to purse seining for tunas are probably less than those due to other types of human activity, which include exploitation of eggs and adults, beach development, pollution, entanglement in and ingestion of marine debris, and impacts of other fisheries.

The populations of olive Ridley, black, and loggerhead turtles are designated as endangered, and those of the hawksbill and leatherback turtles as critically endangered, by the International Union for the Conservation of Nature.

2.7. Sharks and other large fishes

Sharks and other large fishes are taken by both purse-seine and longline vessels. Silky sharks (*Carcharhinus falciformis*) are the most commonly-caught species of shark in the purse-seine fishery. The longline fisheries also take significant quantities of silky sharks, and a Pacific-wide analysis of longline and purse-seine fishing is necessary to estimate the impact of fishing on the stock(s). Preliminary estimates of indices of relative abundance of silky sharks, based on the purse-seine data, show a decreasing trend over the 1994-2004 period for each of the three types of purse-seine sets. It is not known whether this decreasing trend is due to incidental capture by the fisheries, changes in the environment (perhaps associated with the 1997-1998 El Niño event), or other processes. The trend does not appear to be due to changes in the density of floating objects.

A stock assessment for blue sharks (*Prionace glauca*) in the North Pacific has been conducted by scientists of the U.S NMFS and the NRIFSF of Japan. Preliminary results provided a range of plausible values for maximum sustainable yield (MSY) of 1.8 to nearly 4 times the 2001 catch of blue shark per year.

The discards[5] (in metric tons) of sharks and other large fishes in the EPO during 2006, other than those discussed above, by large purse-seine vessels are as follows. Complete data are not available for small purse-seine, longline, and other types of vessels.

	Set type		
	OBJ	**NOA**	**DEL**
Dorado (*Coryphaena* spp.)			
Wahoo (*Acanthocybium solandri)*			
Rainbow runner (*Elagatis bipinnulata*) and yellowtail (*Seriola lalandi*)			

[4] Preliminary data
[5] Preliminary data

Sharks
Rays (Mobulidae and Dasyatidae)
Billfishes
Other large fishes

Apart from the assessments of billfishes, summarized in Sections G-I of this report, and blue shark, there are no stock assessments available for these species in the EPO, and hence the impacts of the bycatches on the stocks are unknown.

The catch rates of species other than tunas in the purse-seine fishery are different for each type of set. With a few exceptions, the bycatch rates are greatest in sets on floating objects, followed by unassociated sets and, at a much lower level, dolphin sets. Dolphin bycatch rates are greatest for dolphin sets, followed by unassociated sets and, at a much lower level, floating-object sets. The bycatch rates of sailfish, manta rays (Mobulidae), and stingrays (Dasyatidae) are greatest in unassociated sets, followed by dolphin sets and then floating-object sets. Because of these differences, it is necessary to follow the changes in frequency of the different types of sets to interpret the changes in bycatch figures. The estimated numbers of purse-seine sets of each type in the EPO during 1989-2006 are shown in Table A-8.

In October 2006, the U.S. National Marine Fisheries Service hosted a workshop on bycatch reduction in the EPO purse-seine fishery. The attendees agreed to support a research proposal seek methods to attract sharks away from floating objects prior to setting the purse seine to reduce bycatch. A feasibility study has been planned. The workshop attendees also supported a suite of field experiments on bycatch reduction devices and techniques. These would include FAD modifications and manipulations, assessing behavioral and physiological indicators of stress, and removing animals from the seine and deck (*e.g.* sorting grids, bubble gates, and vacuum pumps). A third proposal, which was supported by the workshop attendees, involves using IATTC data to determine if spatial, temporal, and environmental factors can be used to predict bycatch in FAD sets and to determine whether time/area closures would be effective in reducing bycatch.

3. OTHER ECOSYSTEM COMPONENTS

3.1. Seabirds

There are approximately 100 species of seabirds in the tropical EPO. Some seabirds associate with epipelagic predators near the sea surface, such as fishes (especially tunas) and marine mammals. Subsurface predators often drive prey to the surface to trap them against the air-water interface, where the prey become available to the birds. Most species of seabirds take prey within a half meter of the sea surface or in the air (flyingfishes (Exocoetidae) and flying squid (Ommastrephidae)). In addition to driving the prey to the surface, subsurface predators make prey available to the birds by injuring or disorienting the prey and by leaving scraps after feeding on large prey. Feeding opportunities for some seabird species are dependent on the presence of tuna schools feeding near the surface.

Seabirds are affected by the variability of the ocean environment. During the 1982-1983 El Niño event, seabird populations throughout the tropical and northeastern Pacific Ocean experienced breeding failures and mass mortalities, or migrated elsewhere in search of food. Some species, however, are apparently not affected by El Niño episodes. In general, seabirds that forage in upwelling areas of the tropical EPO and Peru Current suffer reproductive failures and mortalities due to food shortage during El Niño events, while seabirds that forage in areas less affected by El Niño episodes may be relatively unaffected.

According to the *Report of the Scientific Research Program under the U.S. International Dolphin Conservation Program Act*, prepared by the U.S. NMFS in September 2002, there were no significant temporal trends in abundance estimates over the 1986-2000 period for any species of seabird, except for a downward trend for the Tahiti petrel (*Pseudobulweria rostrata*), in the tropical EPO. Population status and trends are currently under review for waved, black-footed, and Laysan albatrosses.

Some seabirds, especially albatrosses and petrels, are susceptible to being caught on baited hooks in pelagic longline fisheries. Satellite tracking and at-sea observation data have identified the importance of the IATTC area for waved, black-footed, Laysan, and black-browed albatrosses, plus several other species that breed in New Zealand, yet forage off the coast of South America. In the EPO, there is particular concern for the waved albatross because it is endemic to the EPO and nests only in the Galapagos Islands. Data from 12 artisanal longline boats and a survey of observers indicated no significant bycatch of seabirds. Data from the US pelagic longline fishery in the northeast Pacific Ocean indicate that bycatches of black-footed and Laysan albatross occur. Few comparable data for the longline fisheries in the central and southeast Pacific Ocean are available. At the 6th meeting of the IATTC Working Group on Bycatch in February 2007, it was reported that the Spanish surface longline fleet targeting swordfish in the EPO averaged 40 seabird interactions, virtually all resulting in mortality, per million hooks[5] during 1990-2005. In an externally-funded study, the IATTC staff is currently investigating the population status of the black-footed albatross in the entire north Pacific Ocean, taking into account the effects of fisheries bycatch.

3.2. Forage

The forage taxa occupying the middle trophic levels in the EPO are obviously important components of the ecosystem, providing a link between primary production at the base of the food web and the upper-trophic-level predators, such as tunas and billfishes. Indirect effects on those predators caused by environmental variability are transmitted to the upper trophic levels through the forage taxa. Little is known, however, about fluctuations in abundance of the large variety of prey species in the EPO. Scientists from the U.S. NMFS have recorded data on the distributions and abundances of common prey groups, including lanternfishes (Myctophidae), flyingfishes, and some squids, in the tropical EPO during 1986-1990 and 1998-2000. Mean abundance estimates for all fish taxa, and to a lesser extent for squids, increased from 1986 through 1990. Estimates were low again in 1998, and then increased through 2000. Their interpretation of this pattern was that El Niño events in 1986-1987 and 1997-1998 had negative effects on these prey populations. More data on these taxa were collected during the NMFS STAR 2003 and 2006 cruises, and are currently being analyzed.

The Humbodt or jumbo squid (*Dosidicus gigas*) populations in the EPO have increased in size and habitat range in recent years. In addition, in 2002 observers on tuna purse-seine vessels reported increased incidental catches of Humboldt squid caught primarily with skipjack tuna off Peru. Juvenile stages of these squid are common prey for yellowfin and bigeye tunas, as well as other predatory fishes, and they are also voracious predators of small fishes and cephalopods throughout their range. Large Humboldt squid have been observed attacking skipjack and yellowfin inside the purse seine. Not only have these squid impacted the ecosystems that they have expanded into, but Humboldt squid are also thought to have the capability of affecting the trophic structure in pelagic regions. Changes in the Humboldt squid populations could affect the foraging behavior of the tunas and other predators, and perhaps change their catchability. A recent sampling program by the IATTC staff, to examine possible changes in foraging behavior of yellowfin tuna, is described in Section 4.

Some small fishes, many of which are forage for the larger predators, are incidentally caught by purse-seine vessels in the EPO. Frigate and bullet tunas (*Auxis* spp.), for example, are a common prey of many of the animals that occupy the upper trophic levels in the tropical EPO. In the tropical EPO ecosystem model (Section 7), frigate and bullet tunas comprise 10% or more of the diet of eight predator categories. Small quantities of frigate and bullet tunas are captured by purse-seine vessels on the high seas and by artisanal fisheries in some coastal regions of Central and South America. The vast majority of frigate and bullet tunas captured by tuna purse-seine vessels is discarded at sea. The estimated discards[6], in metric tons, of small fishes by large purse-seine vessels with observers aboard in the EPO during 2006 were as follows:

	Set type		
	OBJ	**NOA**	**DEL**
Triggerfishes (Balistidae) and filefishes (Monacanthidae)			
Other small fishes			
Frigate and bullet tunas (*Auxis* spp.)			

3.3. Larval fishes and plankton

Larval fishes have been collected by manta (surface) net tows in the EPO for many years by personnel of the Southwest Fisheries Science Center of the U.S. NMFS. Of the 314 taxonomic categories identified, 17 were found to be most likely to show the effects of environmental change. The occurrence, abundance, and distribution of these key taxa revealed no consistent temporal trends.

The phytoplankton and zooplankton populations in the tropical EPO are variable. For example, chlorophyll concentrations on the sea surface (an indicator of phytoplankton blooms) and the abundance of copepods were markedly reduced during the El Niño event of 1982-1983, especially west of 120°W. Similarly, surface concentrations of chlorophyll decreased during the 1986-1987 El Niño episode and increased during the 1988 La Niña event due to changes in nutrient availability.

The species and size composition of zooplankton is often more variable than the zooplankton biomass. When the water temperatures increase, warm-water species often replace cold-water species at particular locations. The relative abundance of small copepods off northern Chile, for example, increased during the 1997-1998 El Nino event, while the zooplankton biomass did not change.

4. TROPHIC INTERACTIONS

Tunas and billfishes are wide-ranging, generalist predators with high energy requirements, and, as such, are key components of pelagic ecosystems. The ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire accurate depictions of trophic links and biomass flows through the food web in open-ocean ecosystems, and a basic understanding of the natural variability forced by the environment.

Knowledge of the trophic ecology of predatory fishes has historically been derived from stomach contents analysis. Large pelagic predators are considered efficient biological samplers of micronekton organisms, which are poorly sampled by nets and trawls. Diet studies have revealed many of the key trophic connections in the pelagic EPO, and have formed the basis for representing food-web interactions in an ecosystem model (IATTC Bulletin, Vol. 22, No. 3) to explore indirect ecosystem effects of fishing. The most-common prey items of yellowfin tuna caught by purse seines offshore are frigate and bullet tunas, squids and argonauts (cephalopods), and flyingfishes and other epipelagic fishes. Bigeye tuna feed at greater depths than do yellowfin and skipjack, and consume primarily cephalopods and mesopelagic fishes. The most important prey of skipjack overall were euphausiid crustaceans in a study during the late 1950s, whereas a small mesopelagic fish (*Vinciguerria lucetia*) appeared dominant in the diet during the early 1990s. Tunas that feed inshore utilize different prey than those caught offshore. For example, yellowfin and skipjack caught off Baja California feed heavily on red crabs (*Pleuroncodes planipes*). More recently, diet studies have become focused on understanding entire food webs, initially by describing the inter-specific connections among the predator communities, comprising tunas, sharks, billfishes, dorado, wahoo, rainbow runner, and others. In general, considerable resource partitioning is evident among the components of these communities, and researchers seek to understand the spatial scale

[6] Preliminary data

of the observable trophic patterns, as well as the role of climate variability in influencing the patterns.

While diet studies have yielded many insights, stable isotope ratios of carbon and nitrogen provide an ideal compliment to stomach contents for studying food webs. Stomach contents represent a relative snapshot of the most recent meal at the time of day an animal is captured, and under the conditions required for its capture. Stable carbon and nitrogen isotopes, however, integrate information on all components of the diet into the animal's tissues, providing a recent history of trophic interactions and information on the structure and dynamics of ecological communities. Recent stable isosope studies place the average trophic position of yellowfin tuna in the EPO at 4.2-4.5, while previous diet analysis suggest it averages 4.6-4.7.

A short-term study was initiated during the fourth quarter of 2006 to examine the stomach contents of recently-captured yellowfin tuna to detect possible changes in their foraging behavior compared to previous years. Single-species stock assessments are not designed to consider the effect of trophic interactions (*e.g.* predation, competition, and changes in trophic structure) on the stock in question. Prey populations that feed the apex predators also vary over time (see 3.2 Forage), and some prey impart considerable predation pressure on animals that occupy the lower trophic levels (including the early life stages of the apex predators). Stomach samples of a ubiquitous predator, like yellowfin tuna, compared with prevous diet data, can be used to infer changes in prey populations by identifying changes in foraging behavior. Changes in foraging behavior could cause the tunas, for example, to alter the typical depth distributions while foraging, and this could affect their catchability. Stomach samples of yellowfin tuna were collected from purse-seine sets made on fish associated with dolphins. Results are forthcoming.

5. PHYSICAL ENVIRONMENT[7]

Environmental conditions affect marine ecosystems, the dynamics and catchability of tunas and billfishes, and the activities of the fishermen. Tunas and billfishes are pelagic during all stages of their lives, and the physical factors that affect the tropical and sub-tropical Pacific Ocean can have important effects on their distribution and abundance. Environmental conditions are thought to cause considerable variability in the recruitment of tunas and billfishes. Stock assessments by the IATTC have often included the assumption that oceanographic conditions might influence recruitment in the EPO.

Different types of climate perturbations may impact fisheries differently. It is thought that a shallow thermocline in the EPO contributes to the success of purse-seine fishing for tunas, perhaps by acting as a thermal barrier to schools of small tunas, keeping them near the sea surface. When the thermocline is deep, as during an El Niño event, tunas seem to be less vulnerable to capture, and the catch rates have declined. Warmer- or cooler-than-average sea-surface temperatures (SSTs) can also cause these mobile fishes to move to more favorable habitats.

The ocean environment varies on a variety of time scales, from seasonal to interannual, decadal, and longer (*e.g.* climate phases or regimes). The dominant source of variability in the upper layers of the EPO is often called the El Niño-Southern Oscillation (ENSO). The ENSO is an irregular fluctuation involving the entire tropical Pacific Ocean and global atmosphere. It results in variations of the winds, rainfall, thermocline depth, circulation, biological productivity, and the feeding and reproduction of fishes, birds, and marine mammals. El Niño events occur at 2- to 7-year intervals, and are characterized by weaker trade winds, deeper thermoclines, and abnormally-high SSTs in the equatorial EPO. El Niño's opposite phase, often called La Niña, is characterized by stronger trade winds, shallower thermoclines, and lower SSTs. Research has documented a connection between the ENSO and the rate of primary production, phytoplankton biomass, and phytoplankton species composition. Upwelling of nutrient-rich subsurface

[7] Much of the information in this section is from Fiedler, P.C. 2002. Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. Mar. Ecol. Prog. Ser. 244: 265-283.

water is reduced during El Niño episodes, leading to a marked reduction in primary and secondary production. ENSO also directly affects animals at middle and upper trophic levels. Researchers have concluded that the 1982-1983 El Niño event, for example, deepened the thermocline and nutricline, decreased primary production, reduced zooplankton abundance, and ultimately reduced the growth rates, reproductive successes, and survival of various birds, mammals, and fishes in the EPO. In general, however, the ocean inhabitants recover within short periods because their life histories are adapted to respond to a variable habitat.

The IATTC reports monthly average meteorological and oceanographic data on a quarterly basis for the EPO, including a summary of current ENSO conditions. A weak El Niño event was in effect during the fourth quarter of 2004. The weak warm conditions, however, transitioned to neutral conditions during the first quarter of 2005, and continued neutral through the third quarter of 2005. Weak La Niña (or anti-El Niño) conditions developed during the fourth quarter of 2005.

Variability on a decadal scale (*i.e.* 10 to 30 years) also affects the EPO. During the late 1970s there was a major shift in physical and biological states in the North Pacific Ocean. This climate shift was also detected in the tropical EPO by small increases in SSTs, weakening of the trade winds, and a moderate change in surface chlorophyll levels. Some researchers have reported another major shift in the North Pacific in 1989. Climate-induced variability in the ocean has often been described in terms of "regimes," characterized by relatively stable means and patterns in the physical and biological variables. Analyses by the IATTC staff have indicated that yellowfin tuna in the EPO have experienced a lower recruitment regime (1975-1983) and a higher recruitment regime (1984-present). The increased recruitment during the latter period is thought to be due to a shift to a higher productivity regime in the Pacific Ocean. Decadal fluctuations in upwelling and water transport are simultaneous to the higher-frequency ENSO pattern, and have basin-wide effects on the SSTs and thermocline slope that are similar to those caused by ENSO, but on longer time scales.

Environmental variability in the tropical EPO is manifested differently in different regions in which tunas are caught. For example, SST anomalies in the tropical EPO warm pool (5° to 20°N, east of 120°W) have been about one-half the magnitude and several months later than those in the equatorial Pacific NIÑO3 area (5°S to 5°N, 90° to 150°W).

6. AGGREGATE INDICATORS

Recognition of the consequences of fishing for marine ecosystems has stimulated considerable research in recent years. Numerous objectives have been proposed to evaluate fishery impacts on ecosystems and to define overfishing from an ecosystem perspective. Whereas reference points have been used primarily for single-species management of target species, applying performance measures and reference points to non-target species is believed to be a tractable first step. Current examples include incidental mortality limits for dolphins in the EPO purse-seine fishery under the AIDCP. Another area of interest is whether useful performance indicators based on ecosystem-level properties might be developed. Several ecosystem metrics or indicators, including community size structure, diversity indices, species richness and evenness, overlap indices, catch trophic spectra, relative abundance of an indicator species or group, and numerous environmental indicators, have been proposed. Whereas there is general agreement that multiple system-level indicators should be used, there is concern over whether there is sufficient practical knowledge of the dynamics of such metrics and whether a theoretical basis for identifying precautionary or limit reference points based on ecosystem properties exists. Ecosystem-level metrics are not yet commonly used for managing fisheries.

Ecologically-based approaches to fisheries management place renewed emphasis on achieving accurate depictions of trophic links and biomass flows through the food web in exploited systems. Trophic levels (TLs) are used in food-web ecology to characterize the functional role of organisms and to facilitate estimates of energy or mass flow through communities. A simplified food-web diagram, with approximate TLs, of the pelagic tropical EPO, is shown in Figure J-1. Toothed whales (Odontoceti, average TL 5.2), large squid predators (large bigeye tuna and swordfish, average TL 5.2) and sharks (average TL 5.0) are top-level predators. Other tunas, large piscivores, dolphins, and seabirds occupy slightly lower TLs. Smaller epipelagic fishes (*e.g*. *Auxis* spp. and flyingfishes), cephalopods, and mesopelagic fishes are the principal forage of many of the upper-level predators in the ecosystem. Small fishes and crustaceans prey on two zooplankton groups, and the herbivorous microzooplankton (TL 2) feed on the producers, phytoplankton and bacteria (TL 1).

In exploited pelagic ecosystems, fisheries that target large piscivorous fishes act as the ecosystem's apex predators. Over time, fishing can cause the overall size composition of the catch to decline, and, in general, the TLs of smaller organisms are lower than those of larger organisms. The mean TL of the organisms taken by a fishery is a potentially useful metric of ecosystem change and sustainability because it integrates an array of biological information about the components of the system. There has been increasing attention to analyzing the mean TL of fisheries catches and discards since a study demonstrated that, according to FAO landings statistics, the mean TL of the fishes and invertebrates landed globally had declined between 1950 and 1994. Some ecosystems, however, have changed in the other direction, from lower to higher TL communities. Given the potential utility of this approach, TLs were estimated for a time series of annual catches and discards from 1993 to 2003 for three purse-seine fishing modes and the pole-and-line fishery in the EPO. The estimates were made by applying the TLs from the EPO ecosystem model (see Section 7), weighted by the catch data by fishery and year for all model groups from the IATTC tuna, bycatch, and discard data bases. The TLs of the summed catches of all purse-seine and pole-and-line fisheries were fairly constant from year to year (Figure J-2: Average PS+LP). The TL of the floating-object sets varied more than those of the other fisheries, due to the interannual variability in the sizes of the tunas caught and the species compositions of the bycatches in those sets. No relationships between TL estimates and the frequency of different types of sets were observed.

The TLs were also estimated separately for the time series of retained and discarded catches by year for the purse-seine fishery from 1993 to 2003 (Figure J-3). The TLs of the retained catches were quite stable from year to year, while the TLs of the discarded catches varied considerably. The greatest variation occurred for sets on unassociated fish. The low TL of the discarded catches by sets on unassociated fish in 1998 was due to increased bycatches of rays, which feed on plankton and other small animals that occupy low TLs. From 1998 to 2001, the discarded catches of rays gradually declined and those of large sharks increased, resulting in a gradually increasing TL of the discarded catches over that interval. To a lesser degree, the average TLs of the discarded catches of sets on floating objects also increased from 1998 to 2001. That increase was due primarily to increasing bycatches of large wahoo and small dorado.

7. ECOSYSTEM MODELING

It is clear that the different components of an ecosystem interact. Ecosystem-based fisheries management is facilitated through the development of multi-species, ecosystem models that represent ecological interactions among species or guilds. Our understanding of the complex maze of connections in open-ocean ecosystems is at an early stage, and, consequently, the current ecosystem models are most useful as descriptive devices for exploring the effects of a mix of hypotheses and established connections among the ecosystem components. Ecosystem models must be compromises between simplistic representations on the one hand and unmanageable complexity on the other.

The IATTC staff has developed a model of the pelagic ecosystem in the tropical EPO (IATTC Bulletin, Vol. 22, No. 3) to explore how fishing and climate variation might affect the animals at middle and upper trophic levels. The ecosystem model has 38 components, including the principal exploited species (*e.g.* tunas), functional groups (*e.g*. sharks and flyingfishes), and sensitive species (*e.g*. sea turtles). Some taxa are further separated into size categories (*e.g*. large and small marlins). The model has finer taxonomic resolution at the upper trophic levels, but most of the system's biomass is contained in the middle and lower trophic levels. Fisheries landings and discards were estimated for five fishing "gears": pole-and-line, longline, and purse-seine sets on tunas associated with dolphins, with floating objects, and in unassociated schools. The model focuses on the pelagic regions; localized, coastal ecosystems are not adequately described by the model.

Most of the information describing inter-specific interactions in the model comes from a joint IATTC-NMFS project, which included studies of the food habits of co-occurring yellowfin, skipjack, and bigeye tuna, dolphins, pelagic sharks, billfishes, dorado, wahoo, rainbow runner, and others. The impetus of the project was to contribute to the understanding of the tuna-dolphin association, and a community-level sampling design was adopted.

The ecosystem model has been used to evaluate the possible effects of variability in bottom-up forcing by the environment on the middle and upper trophic levels of the pelagic ecosystem. Predetermined time series of producer biomasses were put into the model as proxies for changes in primary production that have been documented during El Niño and La Niña events, and the dynamics of the remaining components of the ecosystem were simulated. The model was also used to evaluate the relative contributions of fishing and the environment in shaping ecosystem structure in the tropical pelagic EPO. This was done by using the model to predict which components of the ecosystem might be susceptible to top-down effects of fishing, given the apparent importance of environmental variability in structuring the ecosystem. In general, animals with relatively low turnover rates were influenced more by fishing than by the environment, and animals with relatively high turnover rates more by the environment than by fishing.

8. ACTIONS BY THE IATTC AND THE AIDCP ADDRESSING ECOSYSTEM CONSIDERATIONS

Both the IATTC and the Agreement on the International Dolphin Conservation Program (AIDCP) have objectives that address the incorporation of ecosystem considerations into the management of the tuna fisheries in the EPO. Actions taken in the past include:

8.1. Dolphins

a. For many years, the impact of the fishery on the dolphin populations has been assessed, and programs to reduce or eliminate that impact have met with considerable success.

b. The incidental mortality of each stock of dolphins has been limited to levels that are insignificant relative to stock sizes.

8.2. Sea turtles

a. A data base on all sea turtle sightings, captures, and mortalities reported by observers has been compiled.

b. In June 2003 the IATTC adopted a Recommendation on Sea Turtles, which contemplates “the development of a three-year program that could include mitigation of sea turtle bycatch, biological research on sea turtles, improvement of fishing gears, industry education and other techniques to improve sea turtle conservation.” In January 2004, the Working Group on Bycatch drew up a detailed program that includes all these elements, and urges all nations with vessels fishing for tunas in the EPO to provide the IATTC with information on interactions with sea turtles in the EPO, including both incidental and direct catches and other impacts on sea turtle populations. Resolution C-04-07 on a three-year program to mitigate the impact of tuna fishing on sea turtles was adopted by the IATTC in June 2004; it includes requirements for data collection, mitigation measures, industry education, capacity building and reporting.

c. IATTC Resolution C-04-05, contains provisions on releasing and handling of sea turtles captured in purse seines. The resolution also prohibits vessels from disposing of plastic containers and other debris at sea, and instructs the Director to study and formulate recommendations regarding the design of FADs, particularly the use of netting attached underwater to FADs.

d. In response to a request made by the Subsecretaría de Recursos Pesqueros of Ecuador, the IATTC began a program, supported by the World Wildlife Fund and the United States government, to mitigate the incidental capture of sea turtles, to reduce the mortality of sea turtles due to longline fishing, and to compare the catch rates of tunas, billfishes, and dorado using circle and J hooks of two sizes. Circle hooks do not hook as many turtles as the J hooks currently used in the longline fishery, and the chance of serious injury to the sea turtles that bite the hooks is reduced because they are wider and they tend to hook the lower jaw, rather than the more dangerous deep hookings in the esophagus and other areas, which are more common with the J hooks. Improved procedures and instruments to release hooked and entangled sea turtles have also been disseminated to the longline fleets of the region.

   Observers have recorded data on almost 400 fishing trips of the vessels that are testing the different hooks. The program is actively running in Peru, Ecuador, Colombia, Panama, Costa Rica, El Salvador, and Guatemala, and plans are afoot in Nicaragua to initiate the program in 2006. Some activities are also being carried out in Mexico. The program in Ecuador is being carried out in partnership with the government and the Overseas Fishery Cooperation Foundation of Japan, while those in other countries are currently funded by US agencies. Initial results show that, in the fisheries that target tunas, billfishes, and sharks (Figure J-4), there was a significant reduction in the hooking rates of sea turtles with the circle hooks, and fewer hooks lodged in the esophagus or other areas detrimental to the turtles. Catch rates of the target species are, in general, similar to the catch rates with the J-hooks. An experiment was also carried out in the dorado fishery (Figure J-4) using smaller circle hooks. There were reductions in turtle hooking rates, but the reductions were not as great as for the fisheries that target tunas, billfishes, and sharks. In addition, workshops and presentations were conducted by IATTC staff members and others in all the countries participating in the program.

8.3. Sea birds

a. IATTC Resolution C-05-01 recommends that CPCs implement, if appropriate, the International Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries; collect and provide information to the Commission on interactions with seabirds; and for the Working Group on Stock Assessment to present to the Commission an assessment of the impact of incidental catches of seabirds resulting from the activities of all the vessels fishing for tunas and tuna-like species in the EPO. This assessment should include an identification of the geographic areas in which there could be interactions between longline fisheries and seabirds.

b. At the 6th meeting of the IATTC Working Group on Bycatch it was recommended that the Working Group suggest possible mitigation measures in areas where seabird distributions and longline effort overlap, and that the IATTC should consider mitigation measures at its June 2007 meeting. It was also recommended that seabird bycatch data be collected from all tuna longliners in the EPO.

c. A population model for black-footed albatross is being developed to assess whether past and present levels of bycatch are likely to significantly affect their populations and to generate a protected species model that can be applied to multiple species and used to provide management advice. IATTC purse-seine observer data are being used also to plot seabird distributions.

8.4. Other species

a. In June 2000, the IATTC adopted a resolution on live release of sharks, rays, billfishes, dorado, and other non-target species.

b. IATTC Resolution C-04-05 instructs the Director to seek funds for reduction of incidental mortality of juvenile tunas, for developing techniques and equipment to facilitate release of billfishes, sharks, and rays from the deck or the net, and to carry out experiments to estimate the survival rates of released billfishes, sharks, and rays.

8.5. All species

a. Data on the bycatches of large purse-seine vessels are being collected, and governments are urged to provide bycatch information for other vessels.

b. Data on the spatial distributions of the bycatches and the bycatch/catch ratios have been collected for analyses of policy options to reduce bycatches.

c. Information to evaluate measures to reduce the bycatches, such as closures, effort limits, *etc*., has been collected.

d. Assessments of habitat preferences and the effect of environmental changes have been made.

9. FUTURE DEVELOPMENTS

It is unlikely, in the near future at least, that there will be stock assessments for most of the bycatch species. In lieu of formal assessments, it may be possible to develop indices to assess trends in the status of these species. The IATTC staff's experience with dolphins suggests that the task is not trivial if relatively high precision is required.

An array of measures has been proposed to study changes in ecosystem properties. This could include studies of average trophic level, size spectra, dominance, diversity, *etc*., to describe the ecosystem in an aggregate way.

The distributions of the fisheries for tunas and billfishes in the EPO are such that several regions with different ecological characteristics may be included. Within them, water masses, oceanographic or topographic features, influences from the continent, *etc*., may generate heterogeneity that affects the distributions of the different species and their relative abundances in the catches. It would be desirable to increase our understanding of these ecological strata so that they can be used in our analyses.

It is important to continue studies of the ecosystems in the EPO. The power to resolve issues related to fisheries and the ecosystem will increase with the number of habitat variables, taxa and trophic levels studied and with longer time series of data.

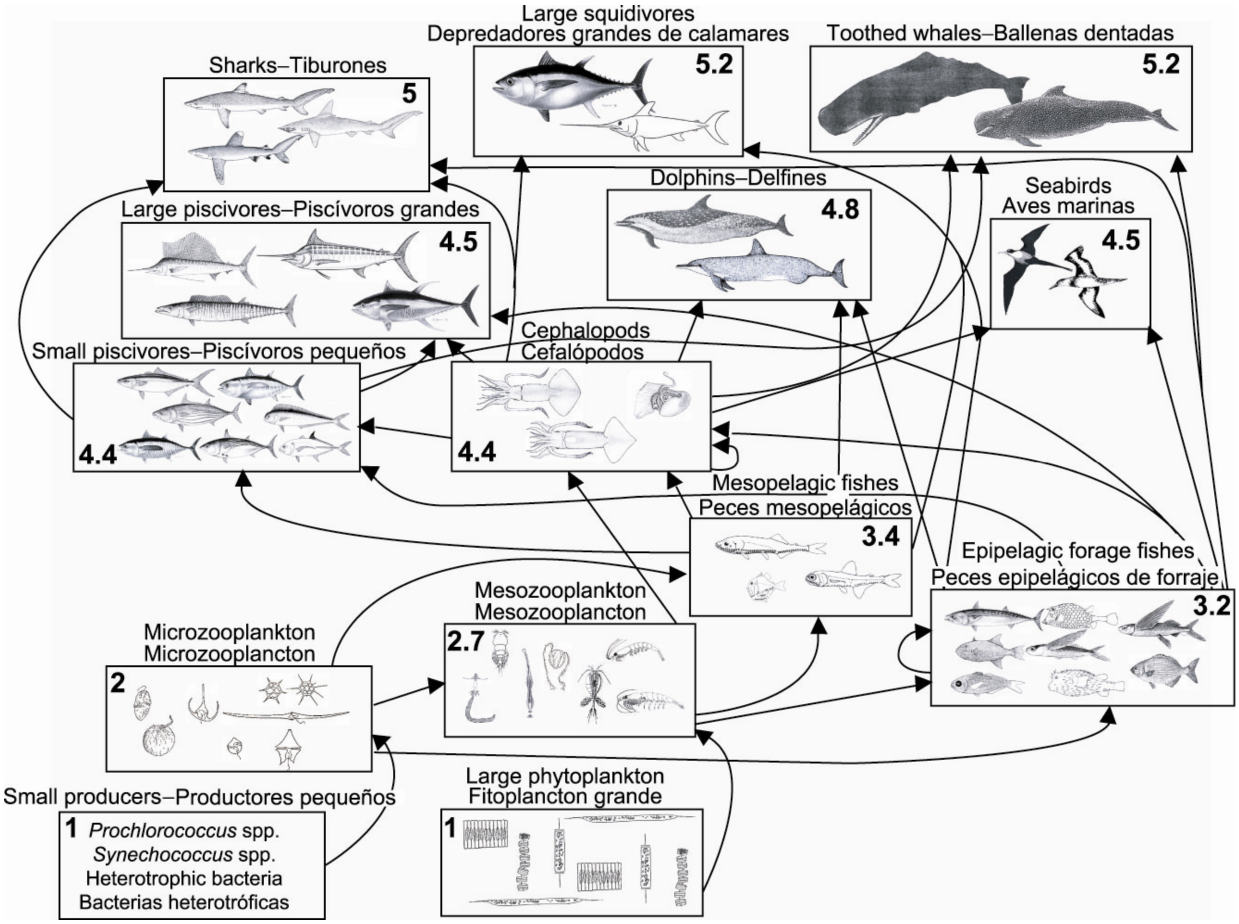

FIGURE J-1. Simplified food-web diagram of the pelagic ecosystem in the tropical eastern Pacific Ocean. The numbers inside the boxes indicate the approximate trophic levels of each group.
FIGURA J-1. Diagrama simplificado de la red trófica del ecosistema pelágico en el Océano Pacífico oriental tropical. Los números en los recuadros indican el nivel trófico aproximado de cada grupo.

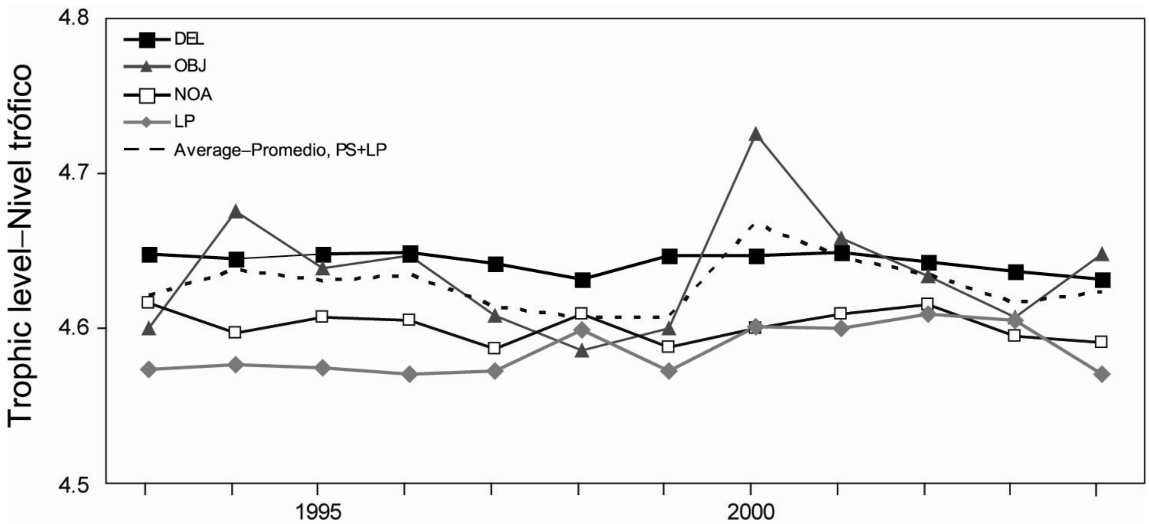

FIGURE J-2. Yearly trophic level estimates of the catches (retained and discarded) by the purse-seine and pole-and-line fisheries in the tropical eastern Pacific Ocean, 1993-2004.
FIGURA J-2. Estimaciones anuales del nivel trófico de las capturas (retenidas y descartadas) de las pesquerías cerquera y cañera en el Océano Pacífico oriental tropical, 1993-2004.

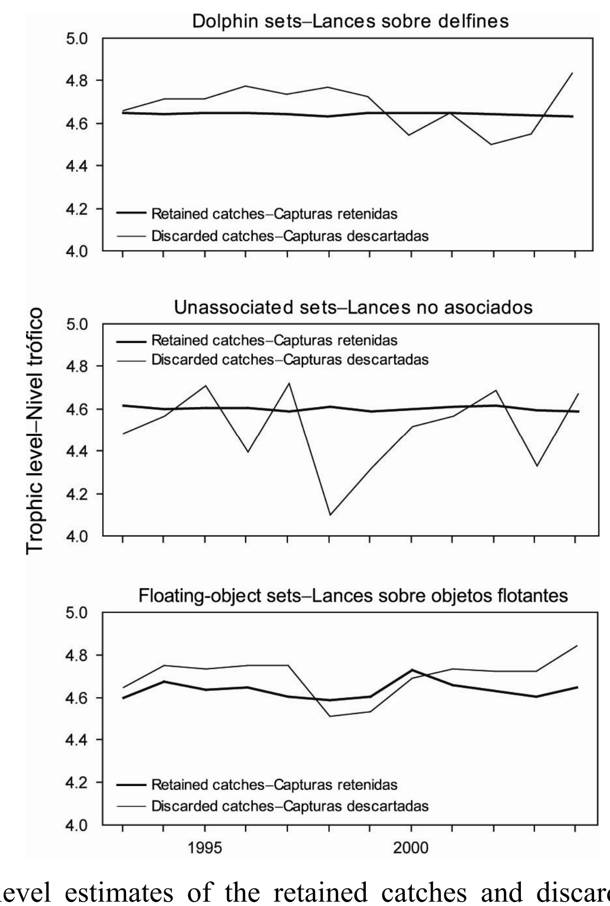

FIGURE J-3. Trophic level estimates of the retained catches and discarded catches by purse-seine fishing modes in the tropical eastern Pacific Ocean, 1993-2004.
FIGURA J-3. Estimaciones del nivel trófico de las capturas retenidas y descartadas por modalidad de pesca cerquera en el Océano Pacífico oriental tropical, 1993-2004.

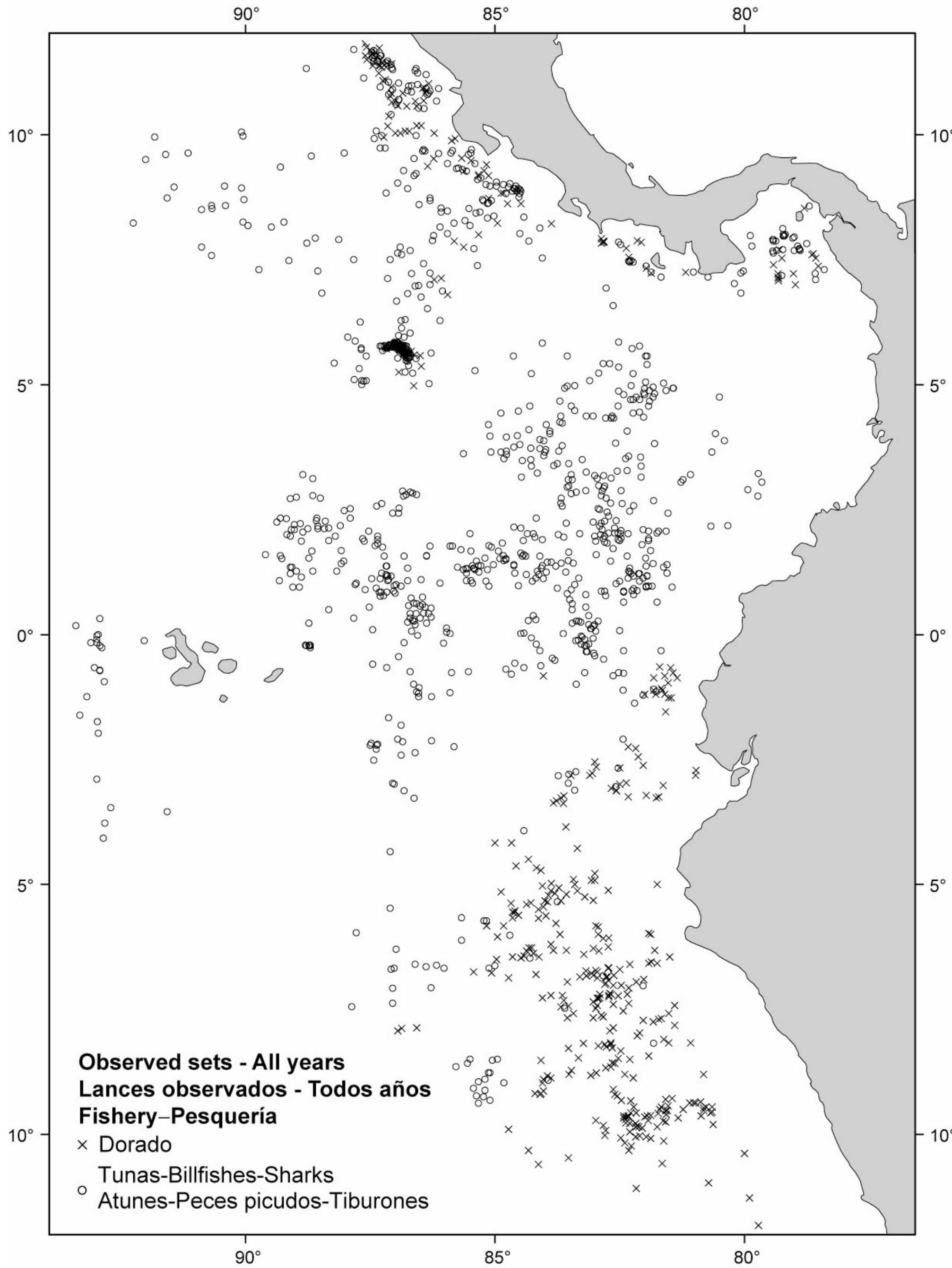

FIGURE J-4. Locations of longline sets by vessels from Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Panama and Peru (part), for which observers recorded data on the catches using different types of hooks.

FIGURA J-4. Posiciones de lances palangreros realizados por buques de Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Panamá y Perú (parte), para los cuales datos de las capturas con distintos tipos de anzuelo fueron registrados por observadores.